Intelligent Power Systems for Human Deep Space Exploration
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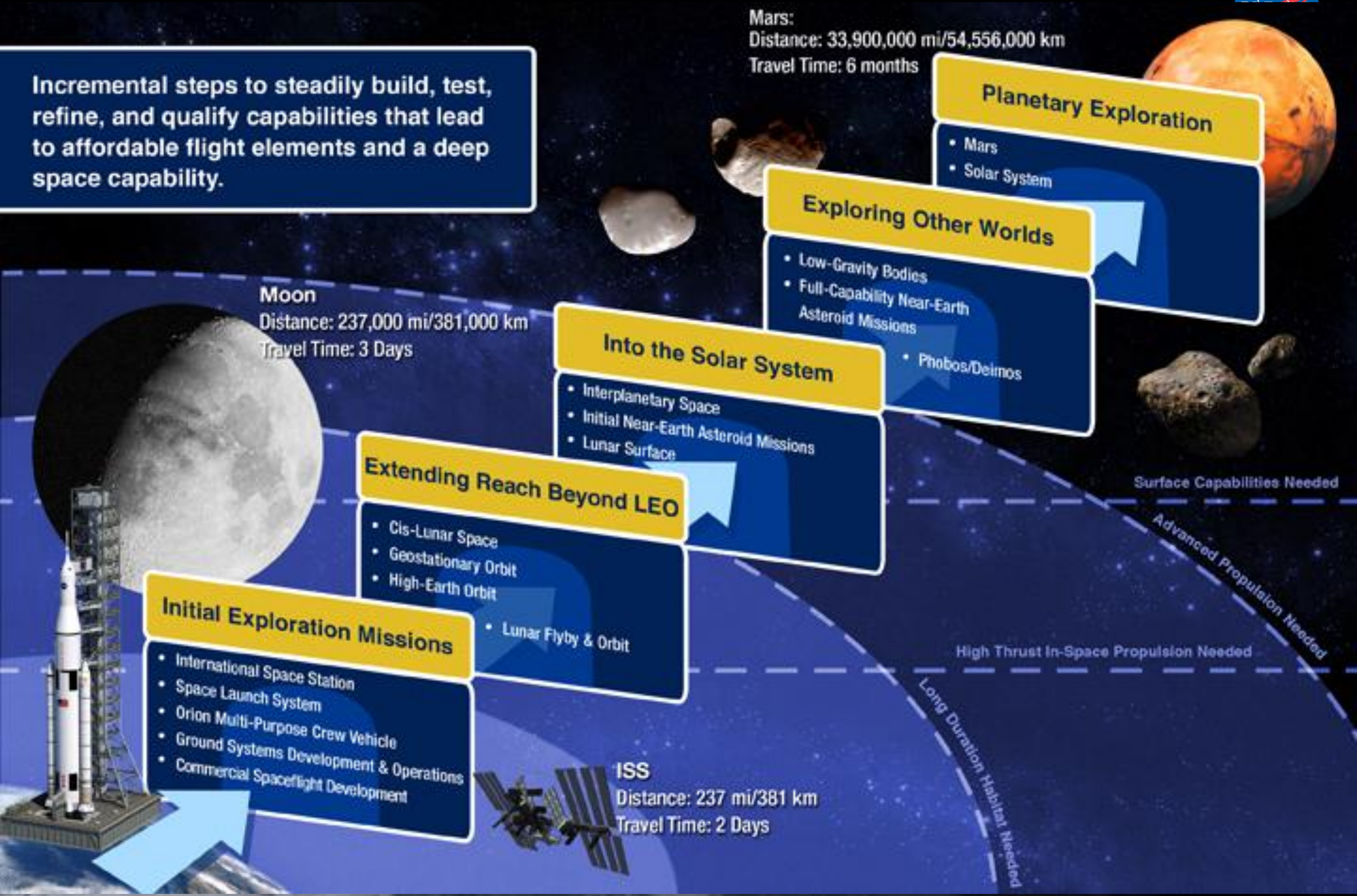
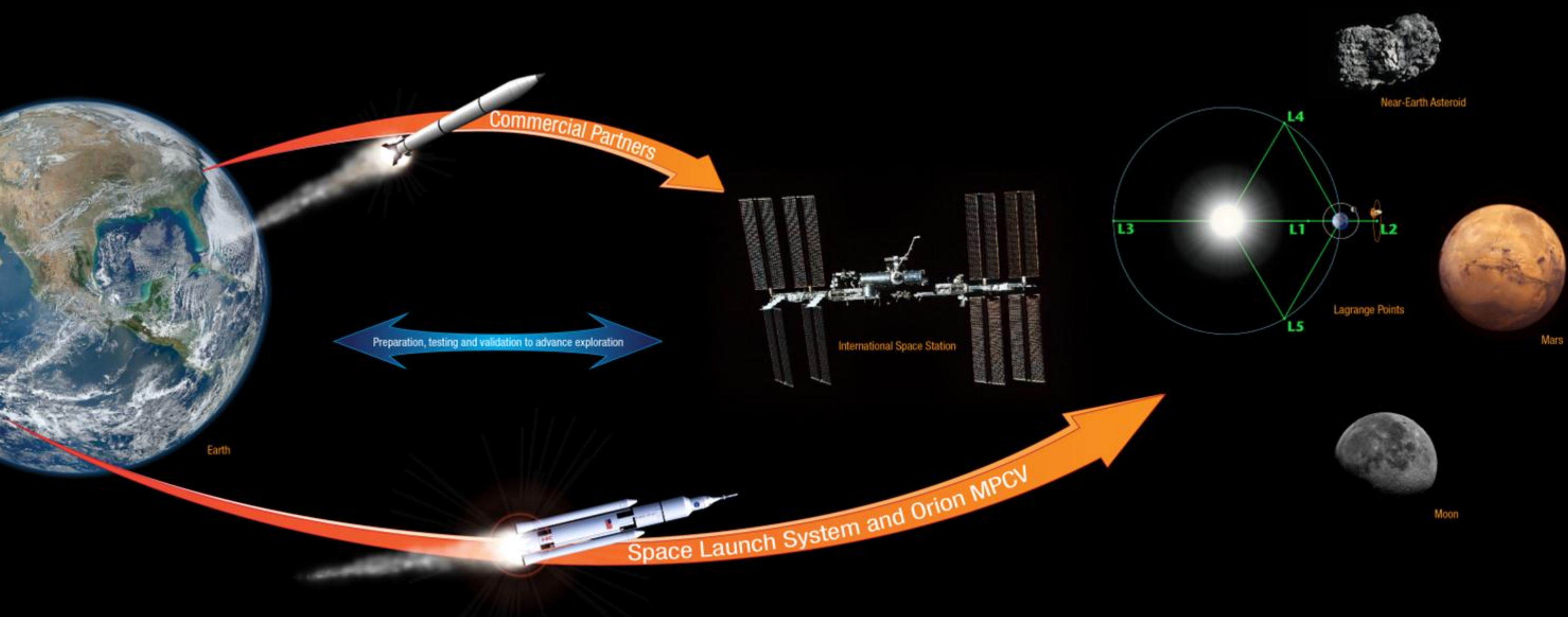
Agenda

- Mission Needs
- What is Intelligent Power ?
- Intelligent Power Architectures
- Development Approach
- Wrap-up


Incremental steps to steadily build, test, refine, and qualify capabilities that lead to affordable flight elements and a deep space capability.
Mars:
Distance: 33,900,000 mi/54,556,000 km
Travel Time: 6 months
Planetary Exploration
• Mars
• Solar System
Exploring Other Worlds
• Low-Gravity Bodies
• Full-Capability Near-Earth Asteroid Missions
• Phobos/Deimos
Into the Solar System
• Interplanetary Space
• Initial Near-Earth Asteroid Missions
• Lunar Surface
Extending Reach Beyond LEO
• Cis-Lunar Space
• Geostationary Orbit
• High-Earth Orbit
• Lunar Flyby & Orbit
Initial Exploration Missions
• International Space Station
• Space Launch System
• Orion Multi-Purpose Crew Vehicle
• Ground Systems Development & Operations
• Commercial Spaceflight Development
Moon
Distance: 237,000 mi/381,000 km
Travel Time: 3 Days
ISS
Distance: 237 mi/381 km
Travel Time: 2 Days
Surface Capabilities Needed
Advanced Propulsion Needed
High Thrust In-Space Propulsion Needed
Long Duration Habitat Needed

The Future of American Human SPACEFLIGHT

National Aeronautics and Space Administration



Human Spaceflight Capabilities

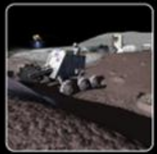
Mobile Extravehicular Activity and Robotic Platform

Deep Space Habitation

Advanced Spacesuits

Advanced Space Communication

Advanced In-Space Propulsion



In Situ Resource Utilization

Human-Robotic Systems

What is the problem?

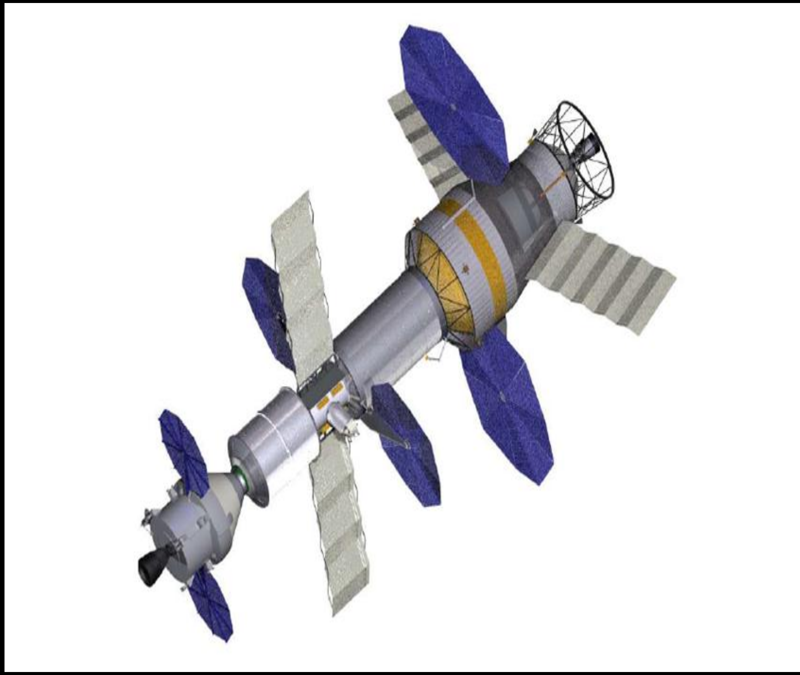
- **Communication and recovery times are longer than any previous experience**

Mission	Duration of Mission After Incident	Communication Latency Time
Deep Space Habitat	9 months to 1 year	15 to 45 mins.
Apollo/Orion	3 – 5 days	1 to 2 sec.
Mount Everest	1 – 2 days	Real time
Deep Sea Submersible	8 hours	Real time
Shuttle	2 – 5 hours	Real time
Submarine	1 – 2 hours	Real time

- **Power Is Most Critical System On Board Vehicle**
  - **System will need a high level of availability**
  - **System will need to operate autonomously for long periods of time**

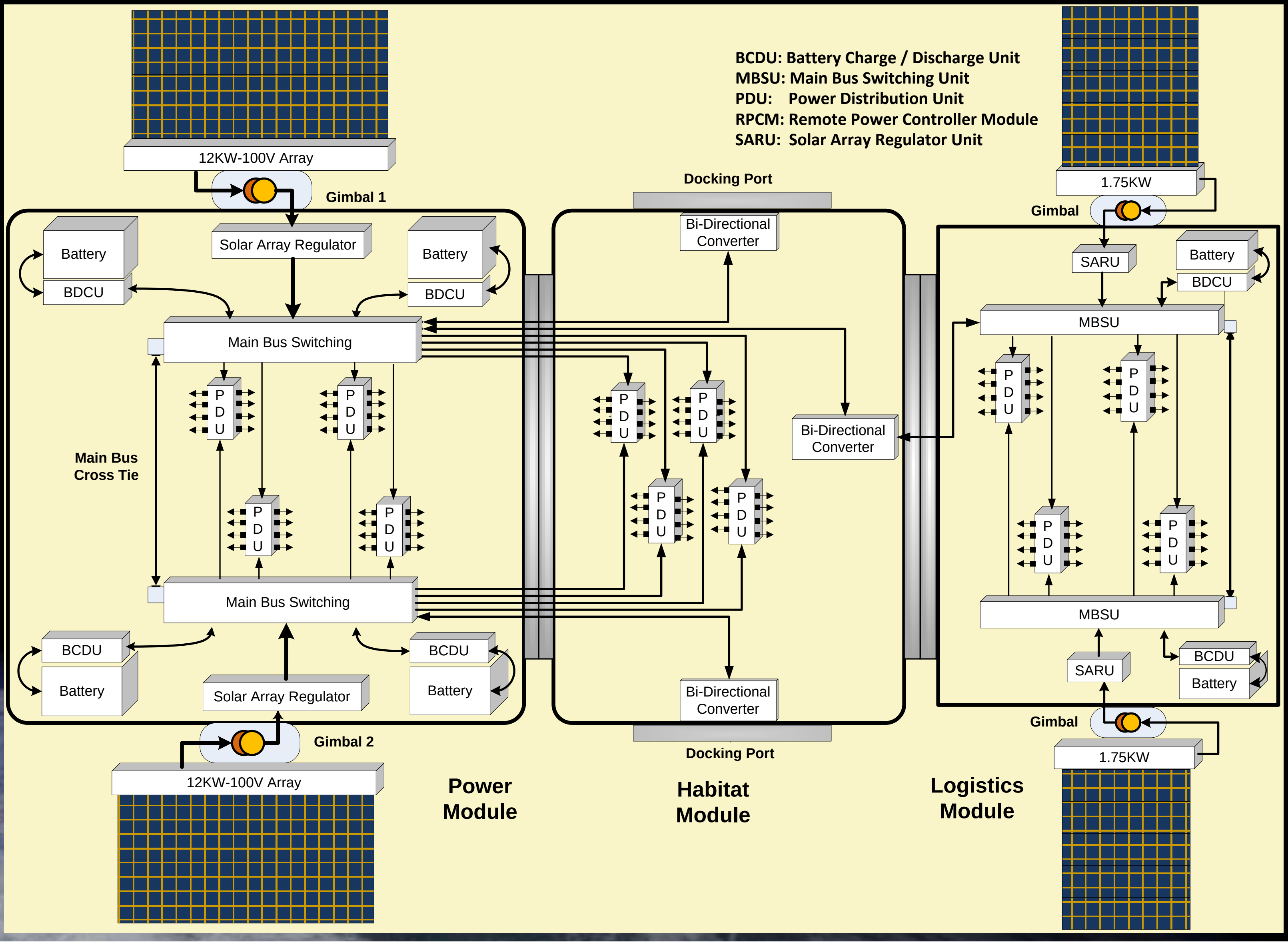
Potential Deep Space Vehicle Power System Characteristics

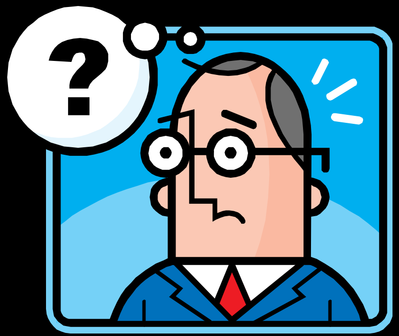
- Power 10 kW average
- Two independent power channels with multi-level cross-strapping
- Solar array power
  - 24+ kW Multi-junction arrays
- Lithium Ion battery storage
  - 200+ amp*hrs
  - Sized for deep space or low lunar orbit operation
- Distribution
  - 120 V secondary (SAE AS 5698)
  - 2 kW power transfer between vehicles



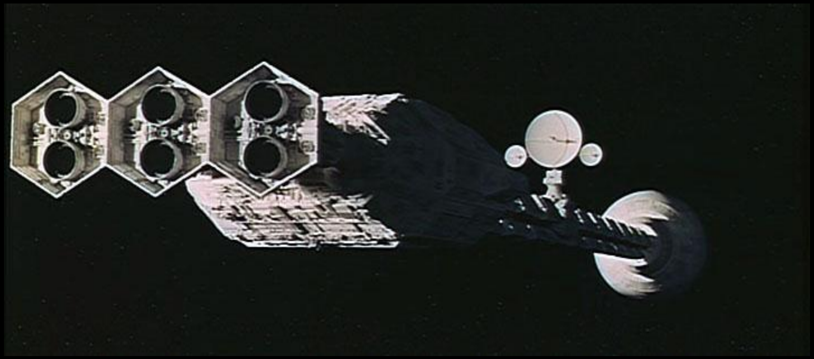
Deep space vehicle concept

Notional Deep Space Vehicle Power Architecture



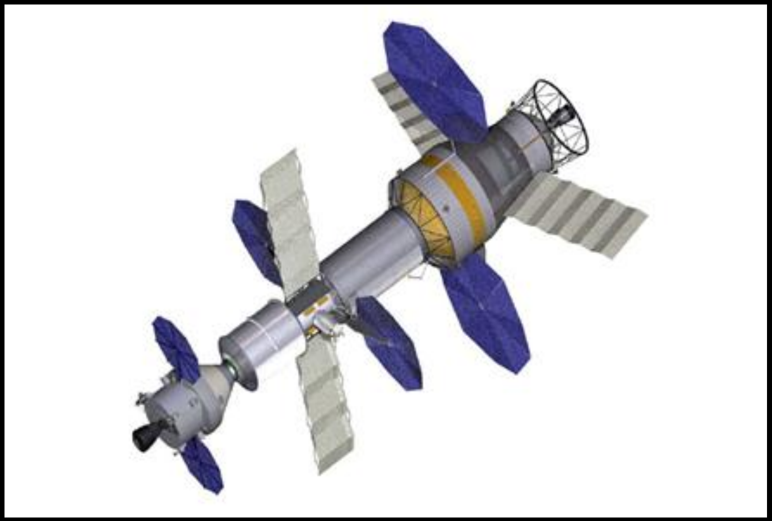


So What is Intelligent Power?



In the 1960's, the operational vision for a spacecraft was routine and mundane for the astronauts – autonomous operation of core systems

What is Intelligent Power?



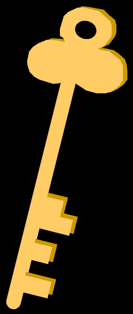
Exploration Systems

Near Earth Systems

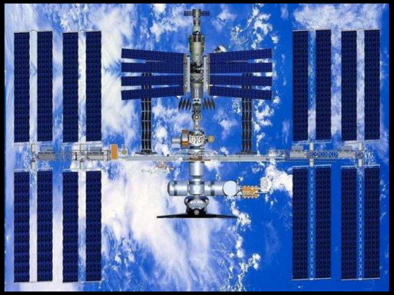
Intelligent Power uses advanced hardware and control technology to autonomously manage and control distributed power generation and storage assets, power distribution networks, and loads for both near earth and space exploration systems.

Intelligent Power System Requirements

- Master Requirements
  - *Power system shall provide up to two years of autonomous operations between habitations*
  - *Power system shall permit humans to consent to any operations / actions above the direct control layer (reactive) during habitation*
- Derived requirements
  - The Intelligent control shall safely manage the energy generation and storage systems
  - The Intelligent control shall safely manage the power distribution system
  - *The Intelligent control shall advise and consent on loads management*
  - *The Intelligent control shall operate the power system in one of three states – Preventative, Restorative and Emergency.*
  - The Intelligent control shall manage the health of the power system
  - During human habitation the Intelligent control shall perform contingency analysis and recommend correction action in response to an anomalous event
  - During uninhabited operation the Intelligent control shall perform contingency analysis and take corrective action in response to an anomalous event.

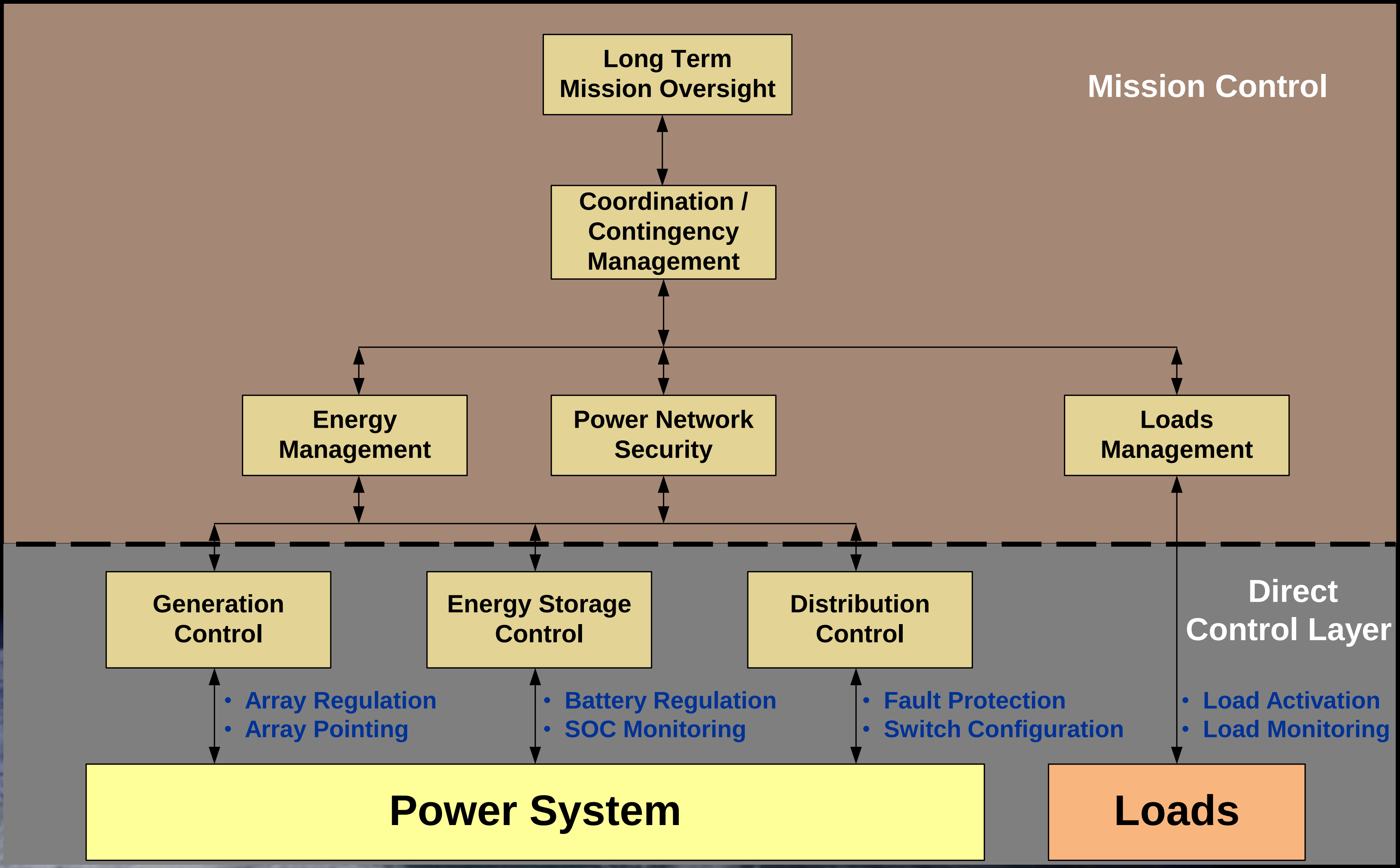


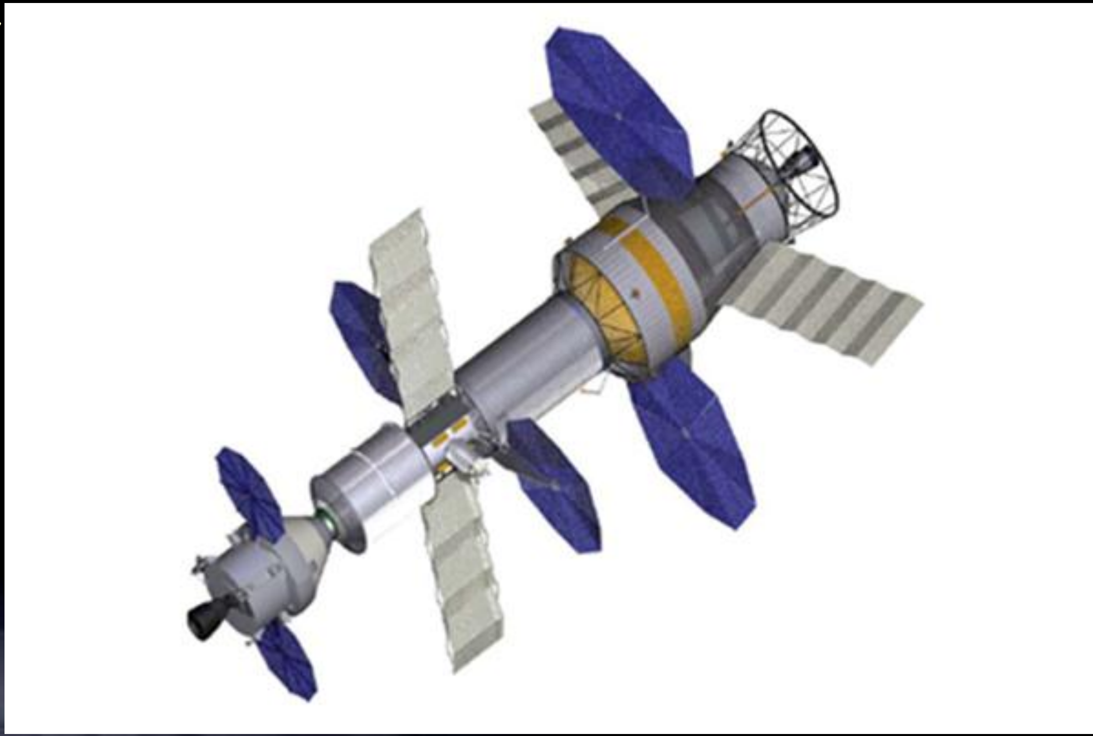
Intelligent Power Architecture



Present power systems rely on continuous real-time support of mission control

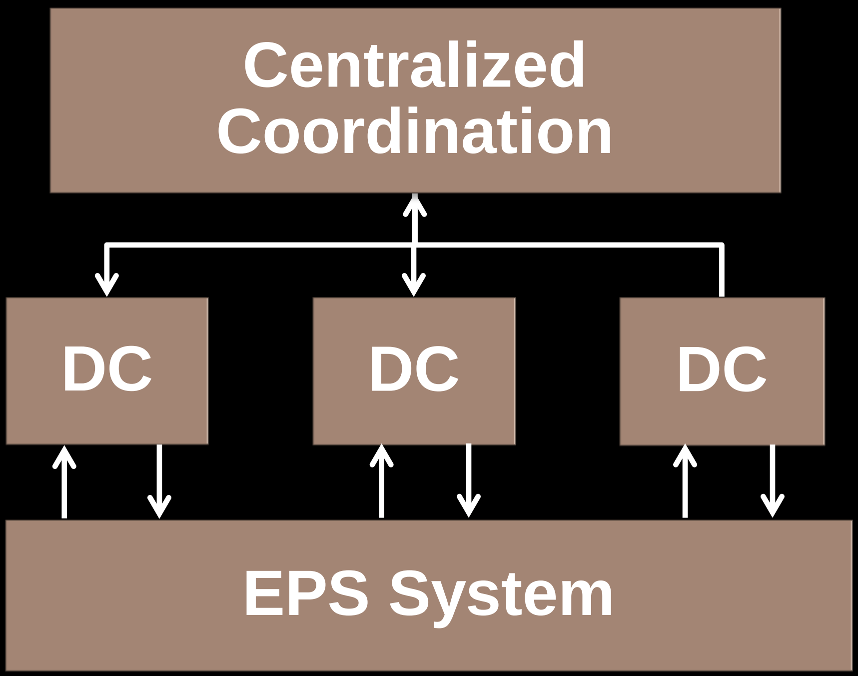
Present Power Management and Control

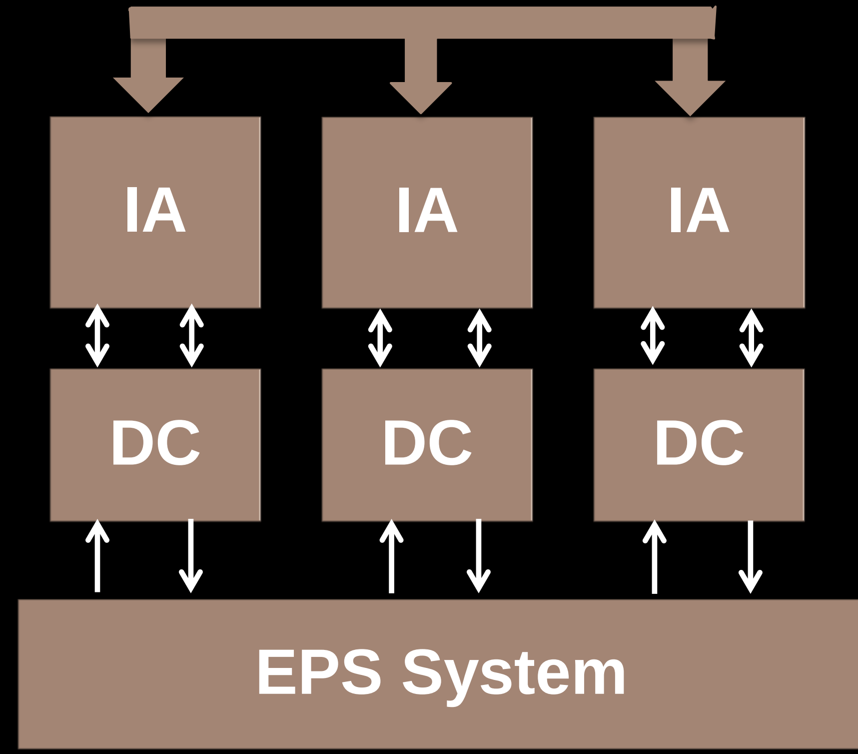




Future space needs to have less dependence on the ground and more on internal intelligence.

Potential Control Architectures



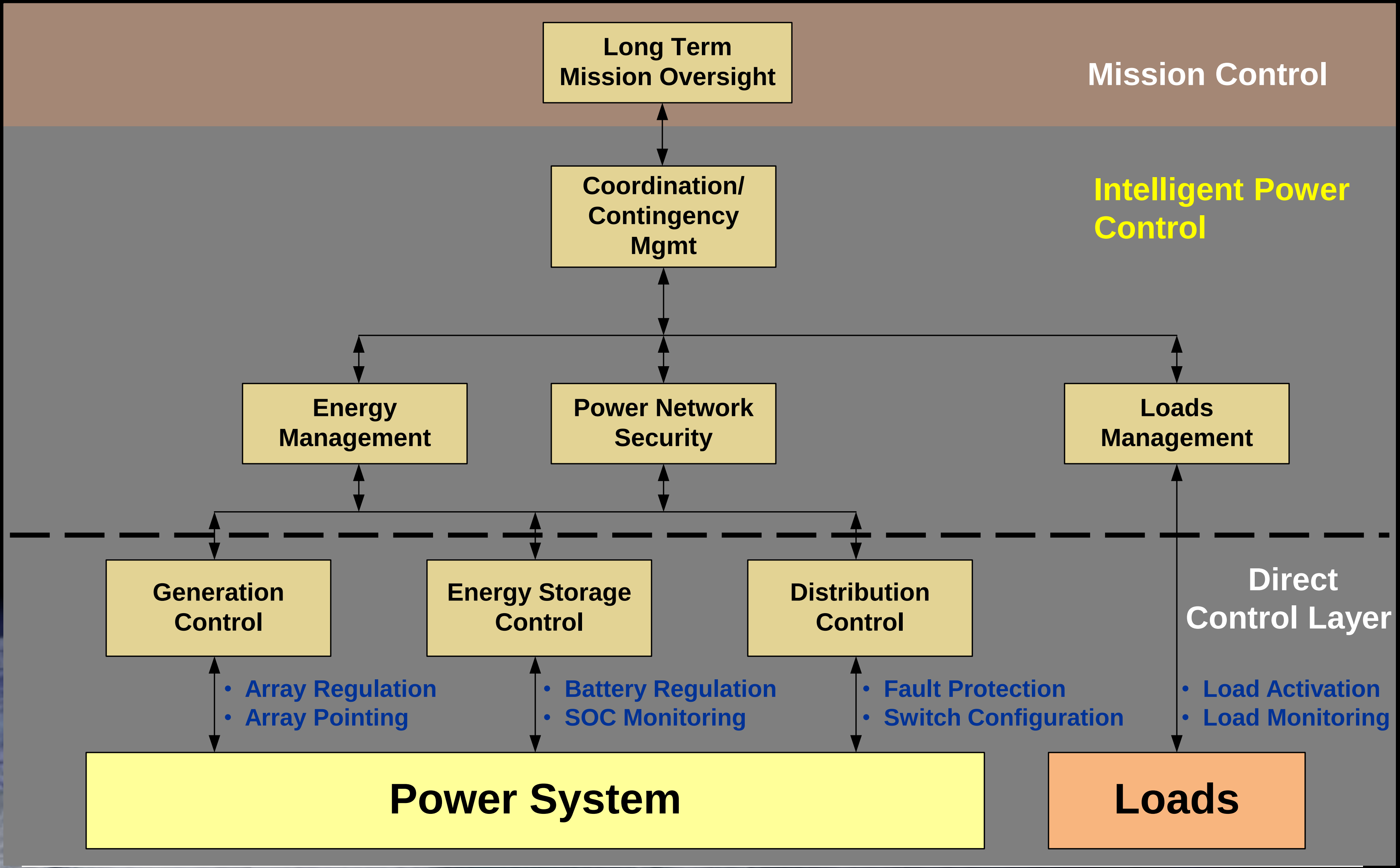


- Distributed Control with Centralized Coordination
- Traditional Hierarchical Multilayer Control

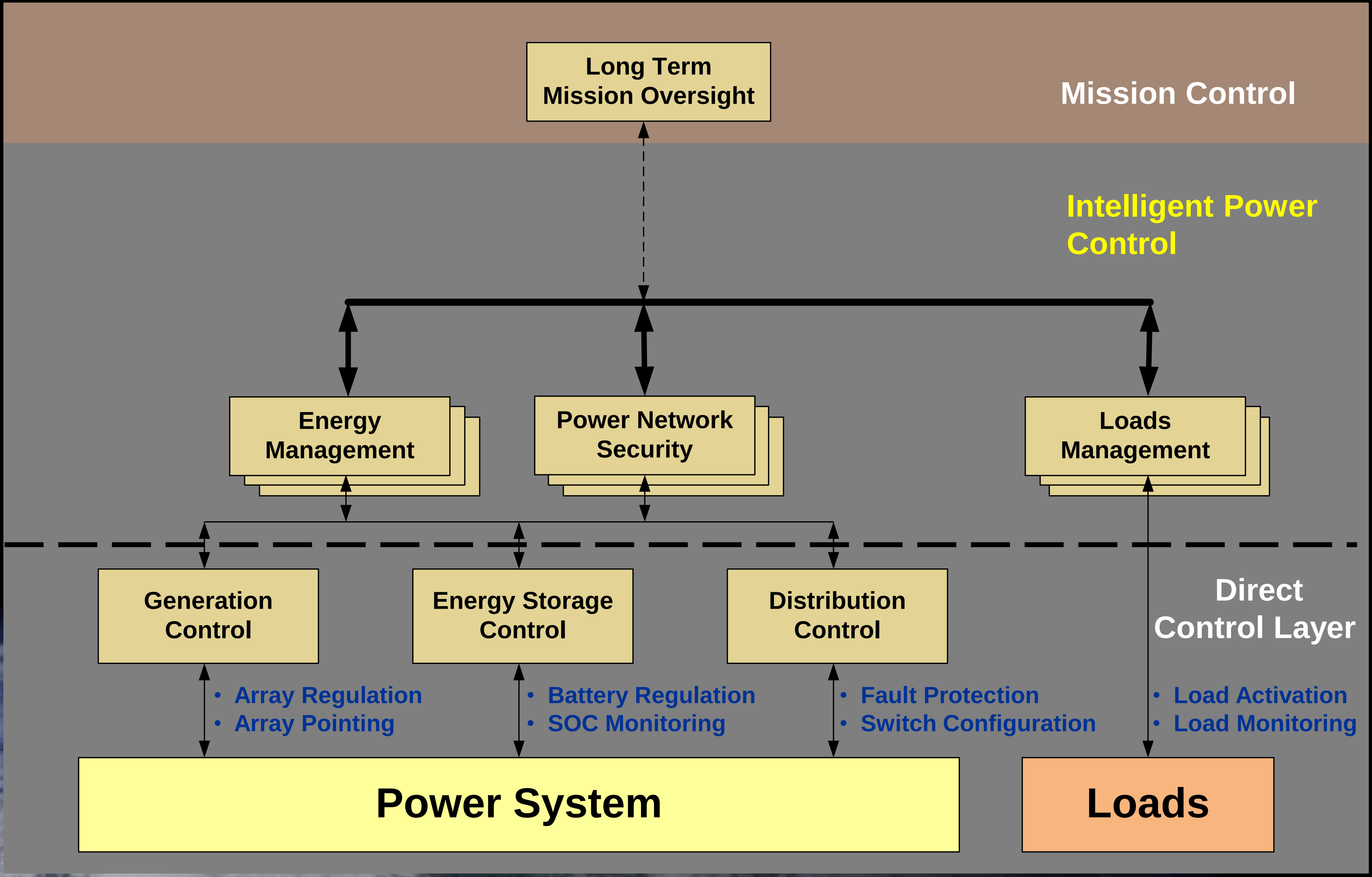
- Distributed Control with Agent Based
- Advanced Concept with Pier to Pier Coordination

DC = Direct Control Layer
IA = Intelligent Agent

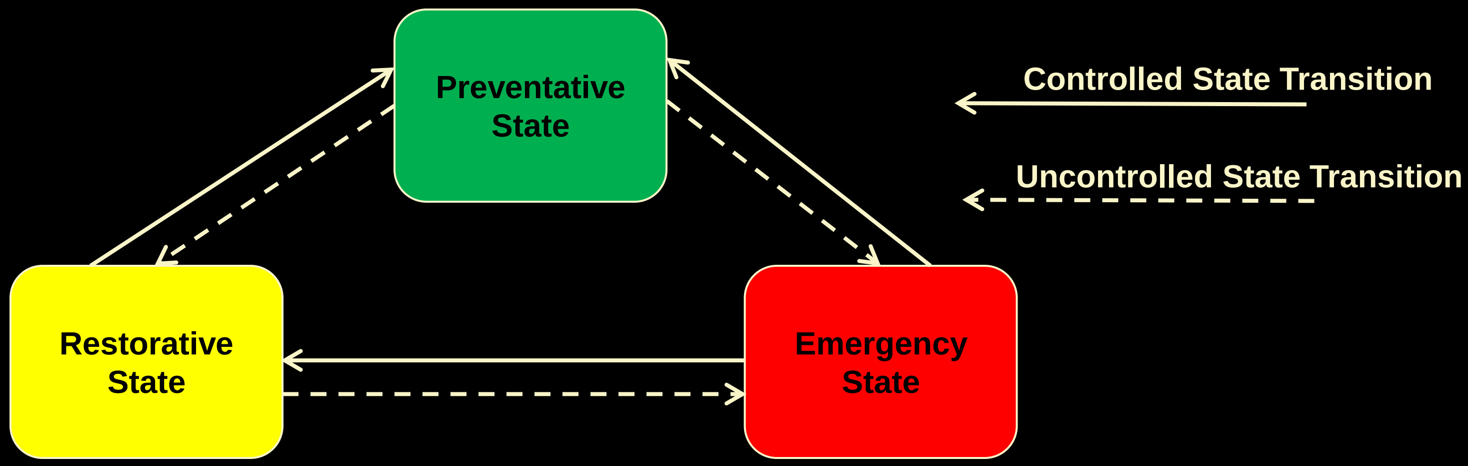
Multi-layer Hierarchical Power System Control



Agent Based Power System Control



Intelligent Power Control States

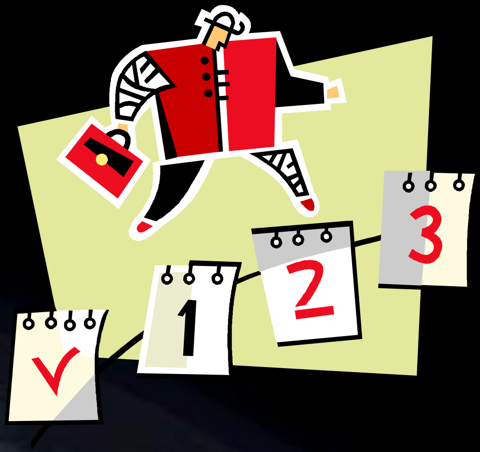


State machine model of power system condition

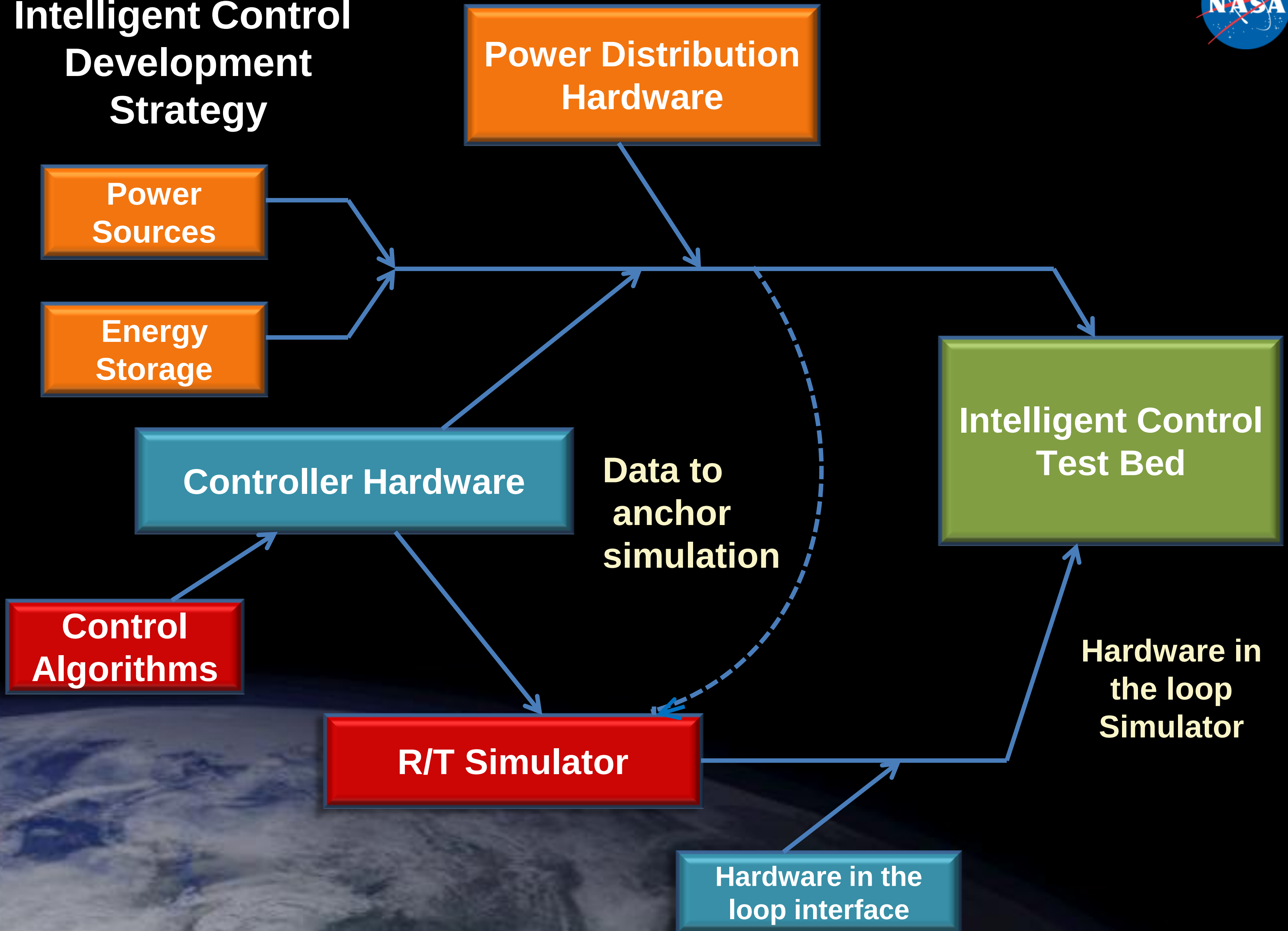
- **Preventative state -- Normal operation, continue indefinitely without interruption**
- **Emergency State – Fault occurs – relieve system stress and prevent further deterioration**
- **Restorative State – System is degraded but safe – restore power flow to all loads in a safe manner in minimum time**

The overall objective of the power control is to service as much demand as possible without exceeding constraints

Intelligent Power Development Approach

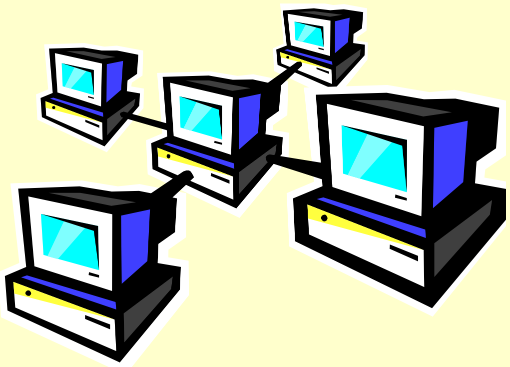


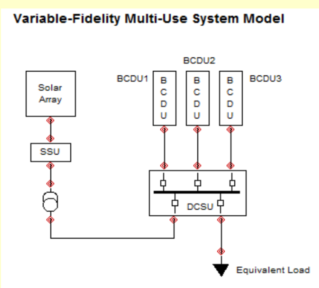
Intelligent Control Development Strategy



Power System Simulation

PC Krause & Associates





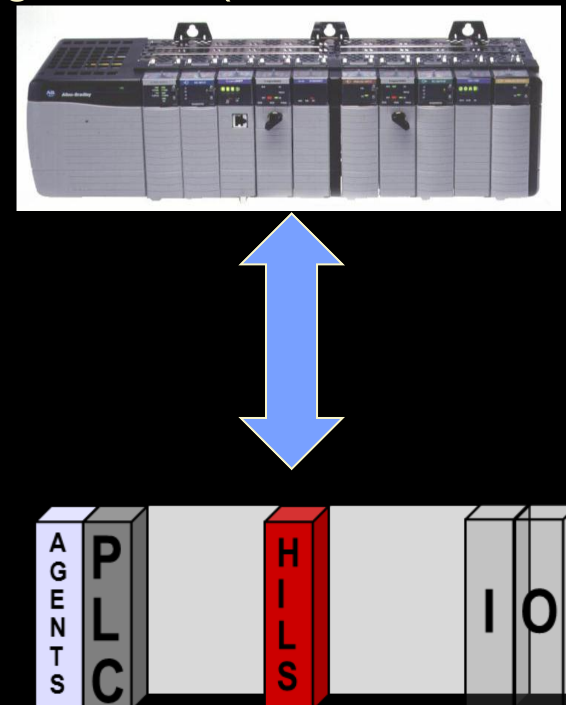
Distributed Heterogeneous Simulation

- 6 High speed multi-core PC’s with 8 processors each
- Total of 48 processors
- PC’s interconnected through high speed Ethernet
- Middleware provides synchronized interconnection of any number of dynamical subsystem simulation processors
- Multi-use model library of spacecraft power system components
- DHS-enabled to support time synchronization and real-time execution
- Support transition from modeling/design environment to hardware/HIL implementation

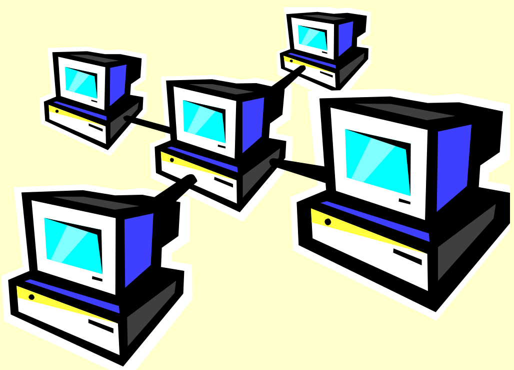
Power System Control

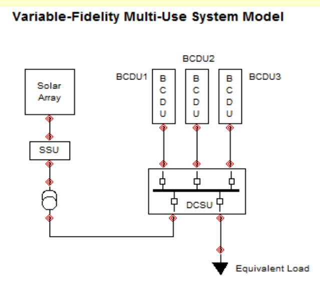
- Objective is develop distributed controls with
  - Centralized coordination
  - Agent based coordination
- Direct layer of reactive control is implemented using the Programmable Logic Controller (PLC)
- Controllers communicate using Common Industrial Protocol over Ethernet, Devicenet or Controlnet
- Discrete / analog outputs permit interfacing with “real power hardware”
- Central coordination or Agent based control is implemented using additional processors
  - Communication is achieved using a “blackboard technique”

ControlLogix (*Rockwell Automation*)



Simulation and Controls





Output Data

Displays

ControlLogix

Sensor Input

Control response

Sensor Input

Control response

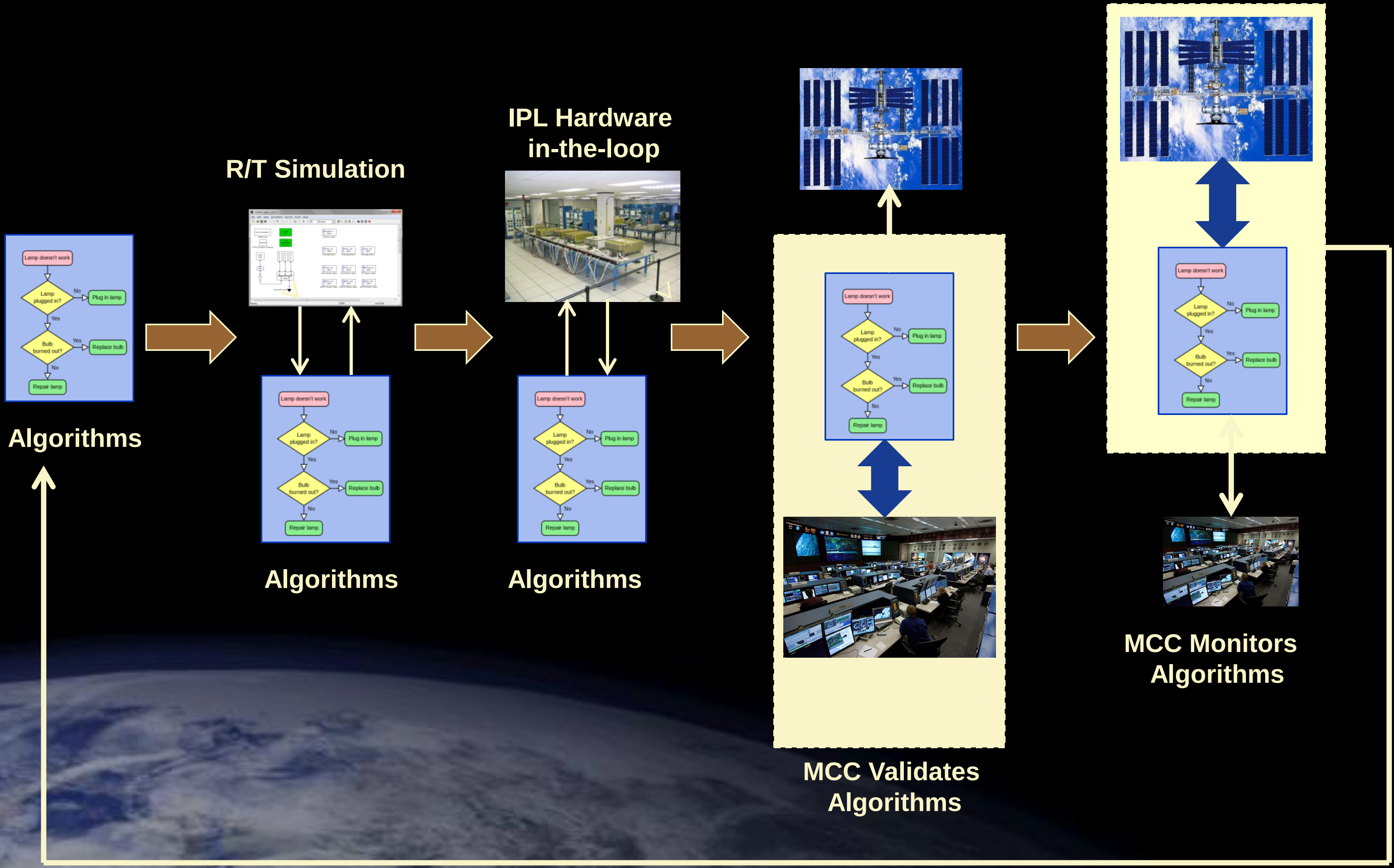
Sensor Input

Control response

Control System

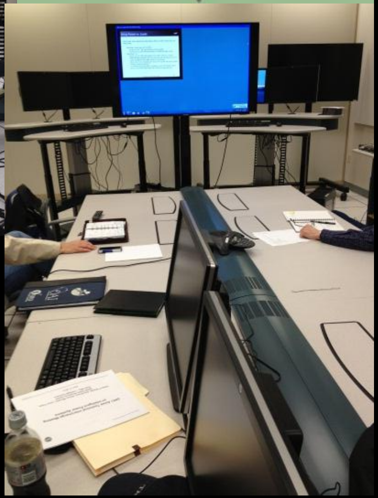
Implementation of control strategies to develop and demonstrate multiple phases of Intelligent Control

Algorithm Development and Verification



Intelligent Power Development Status

- Completed set-up of the Intelligent Power Control Lab
- DHS simulation computers and distributed computing middleware has been installed
- Initial power system simulation is up and running
- Installed Satellite Tool Kit (STK) for orbit navigation and state information
- Distributed controller hardware has been installed
- Initial set of controller requirements have been defined
- On track for an initial controller demonstration at the end of CY 2013

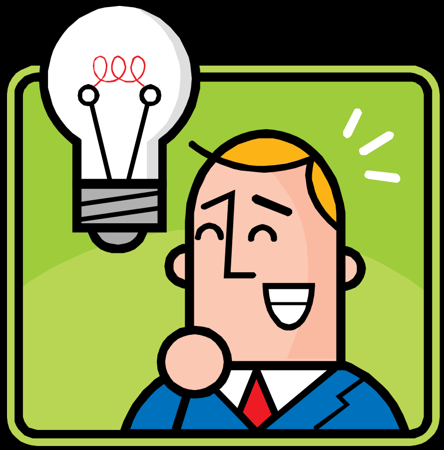


Wrap-up

- We need Intelligent Power Systems for long term operation far from earth

- Several types of control approaches and architectures are possible of achieve the implementation

- Utilization of real-time simulations, hardware in the loop and power system test beds can achieve the goal



References

- 2001: A Space Odyssey Internet Resource Archive

http://www.palantir.net/2001/gallery/mission.html

- Dy Liacco, Tomas E., The Adaptive Reliability Control System, IEEE Transactions on Power Apparatus and Systems, Vol. PAS-86, No. 5, May 1967.
- Maturana, F.P, et.al. Agent-based Testbed Simulator for Power Grid Modeling and Control, IEEE EnergyTech 2012 Conference Proceedings